DOCUMENT RESUME

ED 307 277 TM 013 197

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TITLE The Fleeting Nature of Sex Differences in Spatial Ability.
PUB DATE Mar 89
NOTE 12p.; Paper presented at the Annual Meeting of the American Educational Research Association (San Francisco, CA, March 27-31, 1989).
PUB TYPE Speeches/Conference Papers (150) -- Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS Cognitive Processes; *Computer Assisted Testing; *Data Interpretation; Elementary Secondary Education; High School Students; Junior High School Students; Perception; *Sex Differences; *Spatial Ability; *Visualization
IDENTIFIERS *Intercept Tasks; *Mental Rotation Tests; Spatial Tests

ABSTRACT

Gender differences were examined on three computer-administered spatial processing tasks: (1) the Intercept task, requiring processing dynamic or moving figures; (2) the mental rotation test, employing rotated asymmetric polygons; and (3) the integrating details test, in which subjects performed a complex visual synthesis. Participants were about 450 junior and senior high school students (over half were female). Across the gender group, performance improved substantially for all three tasks between the first session and a retest 1 month later. Although males had an initial advantage in the dynamic task, females were performing as well as males on two of three item types by the second session and had greatly reduced the difference on the third type. In the mental rotation tasks retest, females gained relatively more speed than males, but were still slower than males. There were no gender differences in speed on the visualization test, but males were more accurate, despite the gains females showed at the second test. Results indicate that practice can have large and durable effects on individual and group performance. The differential pattern of change also supports a multifactor view of spatial ability. Data caution against over-interpreting differences in performance, including gender differences, based on single testing sessions. Intercept task data are tabulated for 198 males and 238 females. Mental rotation task data are tabulated for 213 males and 239 females. Detail interpretation task data are tabulated for 204 males and 228 females. Sample task items are provided. (SLD)

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The Fleeting Nature of Sex Differences in Spatial Ability*

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Paper presented at the
Annual Meeting of the American Educational Research Association
in San Francisco, CA

March 1989

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A male superiority in spatial ability is the most consistently reported gender difference in the psychological literature (Maccoby & Jacklin, 1974). The older sex difference literature on spatial ability contained many conflicting reports, in large part because spatial aptitude was treated as more or less unitary. Taking an information processing perspective, several contemporary reviews of the psychometric literature on spatial tests have clearly differentiated several dominant dimensions or factors of spatial aptitude, among the most important are Spatial Relations and Spatial Visualization (Lohman 1979; Lohman, Pellegrino, Alderton & Regian, 1987; McGee, 1979; Pellegrino, Alderton & Shute, 1984; Pellegrino & Kail, 1982; but see Hunt, Pellegrino, Frick & Alderton, 1988). The Spatial Relations factor is defined by simple tests requiring the rapid and accurate mental rotation of objects in either two or three dimensions. Individual differences in Spatial Relations ability are localized chiefly in the speed of process execution. In contrast, the Spatial Visualization factor is defined by complex tests requiring the execution of many cognitive processes or the repeated execution of several processes. Individual differences are mostly in the accuracy of process execution. The more recent gender difference literature has taken into account the distinction between these classes of spatial tests resulting in very consistent findings: males are superior on simple Spatial Relations tests, those requiring speeded mental rotation, but males show only a small and inconsistent advantage on the more complex Spatial Visualization tests (e.g., Linn & Peterson, 1986).

Several studies employing detailed information processing methods have successfully localized the source of gender differences in Spatial Relations items exclusively in the rate of mental rotation (Alderton & Pellegrino, 1985; Kail, Carter & Pellegrino, 1979; Kail, Stevenson & Black, 1984; Tapley & Bryden, 1977; but see Lohman, 1986 for an alternative explanation). Based on Shepard's work (Shepard & Metzler, 1971; Cooper & Shepard, 1973), it is known that response times increase linearly with the angular separation between pairs of stimuli that must be compared. Regressing response times on degree of rotation produces an intercept and slope. The intercept represents the time to encode and compare stimuli then respond to the item. The slope of the function reflects the rate of mental rotation. The information processing research has looked at gender differences in rotating letters and numbers (Kail, Carter & Pellegrino, 1979; Alderton & Pellegrino, 1985), simple line drawings of nonsense figures (Kail et al., 1985; Alderton & Pellegrino, 1985), random asymmetric polygons (Regian & Pellegrino, 1984), and complex 3-dimensional figures (Tapley & Bryden, 1977). In each case, sex differences were found exclusively in the slope parameter, and in each case, males were found to mentally rotate stimuli faster than females. No differences were found in response accuracy or in the rate of encoding and comparing the figures (the intercept). Thus, it appears that the evidence is overwhelmingly in favor of a well localized gender difference favoring males, at least in this aspect of spatial aptitude.

Information processing methodologies have also been applied to several more complex spatial Visualization tasks. Mumaw and Pellegrino (1984) and Alderton and Pellegrino (1988) investigated performance on a task designed to emulate the Minnesota Paper Form Board (MPFB; Likert & Quasha, 1970). The MPFB is a complex Visualization test that requires the construction of puzzles. Mumaw and Pellegrino (1984) reported no sex differences on the task. Alderton and Pellegrino (1988) observed a small male advantage and it was found on an aspect of the task that required mental rotation. Alderton (1986; Alderton & Pellegrino, 1987) investigated performance on a laboratory variant of the Differerential Aptitude Test Battery's Space subtest (Bennett, Seashore & Wesman, 1974). This complex cube folding task revealed no sex differeces on any processing component or in overall accuracy. Thus, information processing analyses of complex visualization tasks reveal few and inconsistent gender differeces. Where a male advantage was found, it was limited to the speed of mental rotation.

There have been many explanations for the gender differences in spatial ability ranging from differences in learning-strategies, educational self-selection, social experience, motivational and affective factors, and hormonal and neurological influences (for reviews see Deaux, 1985; Fausto-Sterling, 1985; McGee, 1979; Sherman, 1978; Wittig & Petersen, 1979). There is no single dominant view of the source(s) of gender differences in spatial ability. However, some recent work has suggested that these differences are mediated by experience. For example, Berg, Hertzog and Hunt (1982) found that the male advantage in rotating block like structures was observed only on the first of four days of testing (each day consisted of 480 trials). Regian and Pellegrino (1984) found that there was a male advantage in the rate of rotating asymmetric polygons but this effect was limited to the first 2 of 7 days of testing (each day consisted of 280 trials). Alderton and Pellegrino (1988) found a similar pattern of results in a rotation task employing alphanumeric and unfamiliar characters; on the first of 4 sessions of testing, females were slower than

males in the rate of mental rotation but achieved near parity by the second session (each day consisted of 192 trials). More importantly, the authors found that even following a 1 to 3 month delay there were still no differences in the rate of mental rotation between males and females. Collectively, these data strongly argue that sex differences in spatial ability, at least for mental rotation items, can be eliminated by practice thus strongly suggesting that experience plays an important role in manifest spatial ability.

The current study looked at gender differences on three computer administered spatial processing tasks. One task required processing dynamic or moving figures. This class of spatial task has shown large gender differences favoring males (Hunt et al., 1987; Pellegrino, 1988). A second task required mental rotation. The final task was a complex synthesis Visualization task. The test battery was administered to a large sample of roughly 450 junior and senior high school students, just over half were female. The average age was 17.15 years for each group. Subjects were administered the three tasks and then returned one month later for retesting. The three tasks are described below.

The *Intercept* task is similar to a video game (for details see Hunt, Pellegrino, Abate, Alderton, Farr, Frick & McDonald, 1987). The top panel of Figure 1 shows an example. On each trial a "UFO" moved at a constant speed from left to right, tracing either a linear, parabolic or sinusoidal function. In the lower right of the computer screen, roughly 2/3s of the distance from the left side, was a "missile." The subjects' task was to intercept the UFO. There were 72 trials, 24 of each of the three different UFO wave forms. The dependent measure was the vertical distance between the UFO and the missile at the point were the UFO crossed the missile's path.

The first table shows the results from the *Intercept* task. The units are pixels times 100 and represent how close on the average the missile came to the UFO – lower values are better. Under the columns labeled "First Testing" are the means and standard deviations (SD) separately for each group and wave form. The column labeled *t* contains *t*–statistics for the difference between males and females. Note that the males were substantially better than the females on this task and for each of the wave forms. The same information for the Second Testing is also presented in the table. Both males and females demonstrate substantial (and significant) improvements between the first and second testing sessions. More importantly, observe that there is no longer a significant difference between the groups on two of the wave forms, and the third wave form reveals a substantial lessening of differences found on the first test. Thus, following the 72 practice trials on the first testing, 1 month later the male advantage is substantially reduced and actually eliminated on two of the problem types.

The *Mental Rotation* test employed asymmetric polygons as shown in the lower 2 panels of Figure 1. Each trial consisted of a pair of polygons with the right member rotated either 0, 25, 50, 75, 100, 125, 150 or 175 degrees counter clockwise from the upright position. There were 128 trials, on half of the trials the two polygons matched ("Same"), for the remaining trials the rotated figure was a mirror image of the standard and thus did not match ("Different"). The dependent measures were accuracy and response latency. In addition, for each subject the mental rotation model was fit to the data producing an intercept, the time to encode, compare and respond to the stimuli, and a slope, the rate of mental rotation.

The data for the *Mental Rotation* task is presented in Table 2 using the same format as Table 1. The first session data provide a replication of previous work. Namely, there are no gender differences in solution accuracy or in the speed of encoding, comparing and responding (intercept) to the stimuli. There is an overall male speed advantage in mean response latency but this is the result of males rotating the figures substantially faster than the females – as evidenced by the significant difference between the groups on the slope parameter. The retest data show that subjects were much faster in the second session. Further, the females have greatly reduced the male advantage in mean latency, which is chiefly due to the reduction in the rate of mental rotation. The slope difference between males and females, although still significant, has dropped from 2.8 msec/degree in the first testing to a trivial 1.0 msec/degree on the retest. Thus, following the 128 practice trials on the first testing, translating into just over 6 minutes of practice ([128 trials * 2.847 seconds]/60 = 6.074 minutes), 1 month later the male advantage is substantially reduced and nearly eliminated.

The *Integrating Details* test presented subjects with small puzzles (Alderton, 1988; Hunt et al., 1987); Figure 2 contains an example. On the first screen of an item, the subject saw either 3, 4, 5 or 6 puzzle pieces with lettered edges. The individual was instructed to connect the edges with matching letters until a single irregular shape was created (the internal lines had to be removed). When finished, a key was

pressed, and the puzzle pieces were replaced by an irregular shape. Subjects had to decide if the presented figure would have been constructed from the puzzle pieces.

Table 3 shows the test and retest data for the *Integrating Details* task. This complex Visualization task produced no significant differences between males and females on either of the latency based measures in the first testing. However, there was a significant male advantage for solution accuracy. This is in contrast to the Spatial Relations (rotation) problems which showed the opposite effect; males were faster but accuracy was equivalent. The retest data shows that everyone had become faster but no gender effects emerged. The accuracy score shows that males still got significantly more items correct than females in the retest. However, on the retest the females had significantly improved their accuracy scores (t [227] = -2.21, p = .022, 2–tailed) over the first session but the males showed no statistically reliable improvement. Thus, following only 32 practice trials in the first testing, 1 month later females showed a significant improvement in accuracy but the males showed no change, although they still held an advantage over the females.

In summary, across gender groups, performance on all three tasks improved substantially between the first session and the 1 month delayed second testing session. In terms of gender differences, each of the tasks showed different sources of gender differences and consequently the pattern of change differed. In the dynamic spatial task, the males showed an across the board advantage, by the second session females were performing as well as males on two of the three item types, and had greatly reduced differences on the third item type. In the first session of the mental rotation task there were no gender differences on accuracy, but consistent with the extant literature, males had a much faster rate of mental rotation. By the second session, the females had gained relatively more speed than the males, and demonstrated a rate of mental rotation nearly equivalent to the males, although there was still a significant difference between the groups. In contrast, on the complex Visualization task, there were no gender differences on the first or second testing in terms of the speed of item solution. However, males accurately solved more problems than the females on both the first and second sessions but only the females showed a significant gain in the second session.

These data make three important points. First, at least in terms of spatial problem solving, even small amounts of practice have profoundly beneficial effects on performance that appear to be quite durable. Second, the differential pattern of change within and across tasks strongly support a a multifactor view of spatial ability. It is not unitary and important information may be lost by treating it as such. There is not a uniform male advantage on all types of spatial problem solving tasks nor is there a uniform locus of gender differences across all spatial tasks. Finally, very small amounts of practice, at least on some tasks, are capable of eliminating many observed gender differences and the changes appear to be durable.

These data cannot explain why males initially out–perform females on spatial tests, or any test for that matter. However, the data do caution against over–interpreting differences observed in test scores obtained in single and usually brief testing sessions. The data show that practice, and therefore experience and training, can have large and durable effects on individual and group performance. The prevailing interpretation of an ability test score is that it is an estimate of a stable and limiting trait of the individual, a *fait accompli*. Therefore, when group differences are observed, there is the tendency to look for stable and limiting characteristics of the groups for an explanation of why the differences exist. These data suggest a more maleable portrayal of abilities than the trait view permits. Accepting abilities as changeable as a starting point, alters the interpretation of test scores and poses a very different question. Instead of seeking an explanation for the differences, the question becomes, what experiences or instructional intervention can ameliorate performance. This view and the resulting question is more in line with educational goals.

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Intercept Task							
		First Testing			Second Testing		
Wave Form	**Group**	**Mean**	**(SD)**	***t***	**Mean**	**(SD)**	***t***
Line	Female	510.1	(214.9)		432.4	(203.5)	
	Male	356.4	(175.2)	8.07	303.0	(173.4)	7.00
	Combined	440.3	(212.0)		371.1	(200.7)	
Parabola	Female	959.6	(299.5)		927.0	(316.5)	
	Male	893.8	(294.9)	2.30	879.4	(311.7)	1.58 ^{NS}
	Combined	929.7	(298.9)		905.4	(315.0)	
Sine	Female	1022.6	(231.1)		964.0	(212.3)	
	Male	968.0	(156.8)	2.82	956.2	(176.1)	0.41 ^{NS}
	Combined	997.8	(202.4)		960.4	(196.5)	

Note: *Female N = 238, Male N = 198, Combined N = 436*

Mental Rotation Task

		First Testing			Second Testing		
Measure	**Group**	**Mean**	**(SD)**	***t***	**Mean**	**(SD)**	***t***
Accuracy	Female	.949	(.043)		.964	(.039)	
	Male	.951	(.047)	-.43 ^{NS}	.964	(.033)	-.03
	Combined	.950	(.045)		.964	(.037)	
Latency	Female	2.971	(.767)		1.663	(.480)	
	Male	2.708	(.808)	3.55	1.476	(.398)	4.48
	Combined	2.847	(.797)		1.575	(.452)	
Intercept	Female	1.475	(.438)		.999	(.234)	
	Male	1.448	(.493)	0.62 ^{NS}	.980	(.199)	1.18 ^{NS}
	Combined	1.462	(.464)		.990	(.215)	
Slope*	Female	.0084	(.006)		.0046	(.003)	
	Male	.0056	(.005)	4.62	.0036	(.003)	2.89
	Combined	.0071	(.006)		.0040	(.003)	

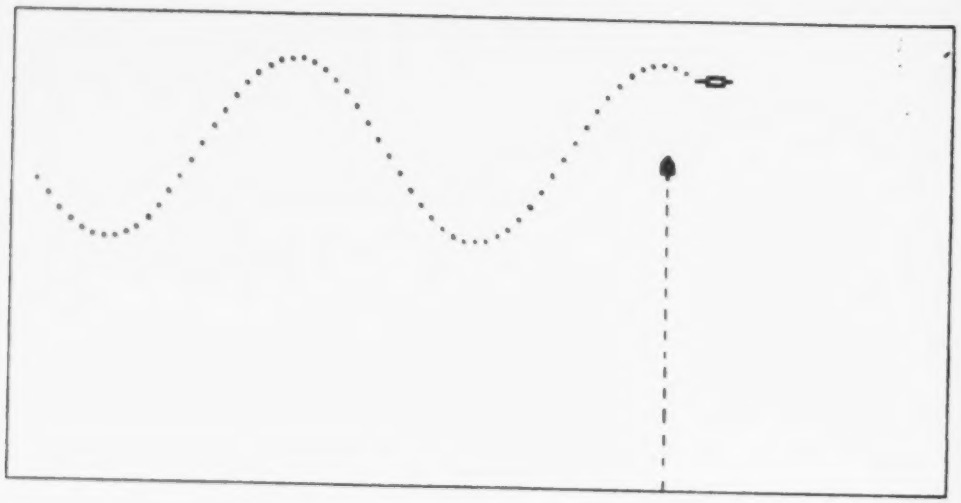
* The units for the slope are in milliseconds per degree of rotation and the average number of degrees of rotation per item is 87.5.

Note: *Female N = 239, Male N = 213, Combined N = 452*

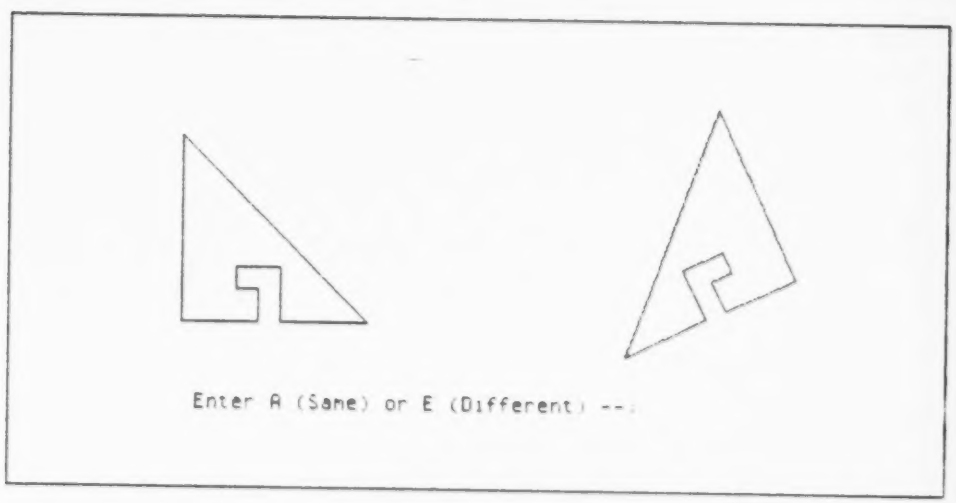
Integrating Details Task							
		First Testing			Second Testing		
Measure	**Group**	**Mean**	**(SD)**	***t***	**Mean**	**(SD)**	***t***
Accuracy	Female	.676	(.143)		.691	(.139)	
	Male	.734	(.133)	-4.43	.745	(.142)	-3.03
	Combined	.703	(.141)		.716	(.143)	
Log Integrate RT	Female	1.113	(.197)		.977	(.202)	
	Male	1.094	(.199)	0.98 NS	.949	(.174)	1.54 NS
	Combined	1.104	(.198)		.964	(.189)	
Log Decision RT	Female	.443	(.128)		.334	(.131)	
	Male	.436	(.149)	0.57 NS	.321	(.127)	1.01 NS
	Combined	.440	(.138)		.328	(.129)	

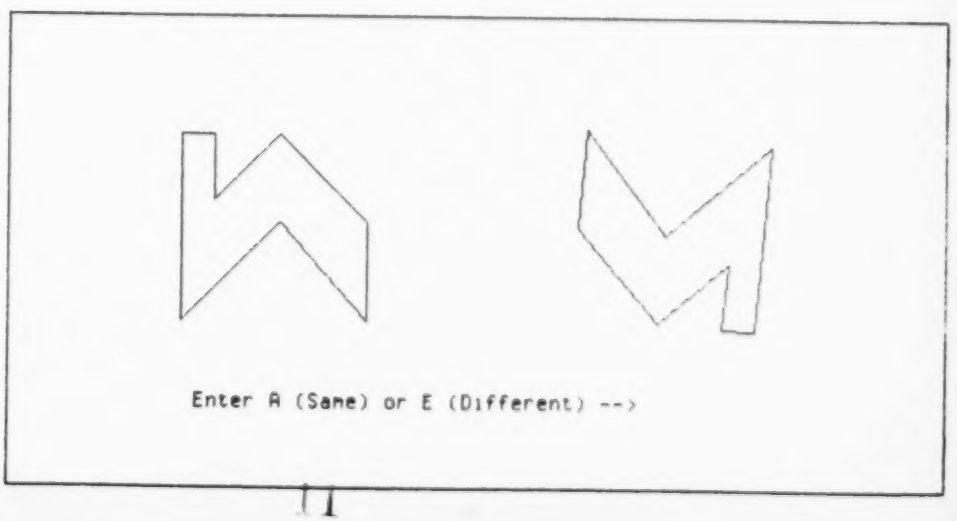
Note: *Female N = 228, Male N = 204, Combined N = 432*

Intercept



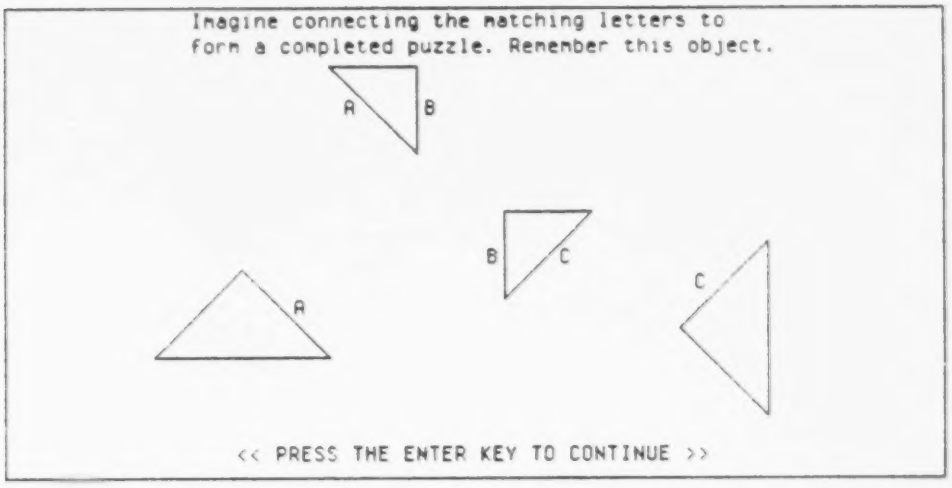
Mental Rotation





Integrating Details

First Screen



Second Screen